
Limb Salvage *Versus* Traumatic Amputation

A Decision Based on a Seven-part Predictive Index

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In severe traumatic injuries to the lower extremity, it is often a difficult decision to attempt heroic efforts aimed at limb salvage or to amputate primarily. To answer this question, the authors performed a 5-year review of 70 limbs in 67 patients. Patients were identified as presenting with major lower extremity trauma and an associated arterial injury. Nineteen (27%) of the 70 limbs were amputated. Limb salvage was not related to the presence or absence of shock and order of repair (orthopedic or vascular). No statistical difference was noted between the time of injury to operative repair in either the amputated or limb salvage group. Limb salvage was related to warm ischemia time and the quantitative degree of arterial, nerve, bone, muscle, skin, and venous injury. A limb salvage index (LSI) was formulated based on the degree of injury to these systems. All 51 patients with an LSI score of <6 had successful limb salvage ($p < 0.001$). All 19 patients with an LSI score of 6 or greater had amputations ($p < 0.001$). Although statistics cannot replace clinical judgment, this index can be a valuable objective tool in the evaluation of the patient with a severely traumatized extremity.

SEVERE TRAUMATIC INJURIES to the lower extremities have proven to be a profound challenge to the surgeon. With the high incidence of multiple systems involved (integument, nerve, bone, and vascular structures), these injuries require a multidisciplinary approach for appropriate management. With multiple surgical specialties represented in the care of these patients, the General/Trauma surgeon usually assumes the role of team leader. Complex decisions inevitably center around whether to attempt heroic efforts aimed at limb salvage or to proceed with primary amputation. Ongoing advances in on-scene trauma management, vascular reconstruction, microsurgical techniques, skeletal fixation, antibiotic therapy, and air ambulance systems have fre-

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quently led to more aggressive attempts at limb salvage in an otherwise doomed extremity. Sometimes "successful" reconstruction takes place, only for the patient to have severe functional deficits that ultimately lead to secondary amputation. This may not occur until months after exhaustive efforts by both patient and surgeon to save a limb. The debts incurred by these patients may be overwhelming, and financial obligations may never be met.

The objective of this study was to identify variables that may ultimately influence the outcome of a severely traumatized extremity with arterial compromise. This presumably would assist the surgeon in the initial decision-making process about whether to pursue extensive reconstruction efforts.

Patients and Methods

During a 5-year period from 1985 to 1990, 67 patients presented to Erlanger Medical Center, Chattanooga, Tennessee with 70 limbs having sustained major lower extremity arterial injury. Of the 70 limbs, 51 (73%) were salvaged and 19 (27%) sustained either primary (11), secondary (6), or functional (2) amputation. A limb was designated as a functional amputation if successful revascularization and wound healing occurred only to have a useless, nonfunctional extremity without weight-bearing ability, and with absence of motor and sensory function. The reasons for failure were analyzed in those limbs for which limb salvage was attempted, as well as the extent of injury in those limbs for which primary amputation was performed.

Presented at the 102nd Annual Scientific Session of the Southern Surgical Association, Boca Raton, Florida, December 3-6, 1990.

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Accepted for publication December 24, 1990.

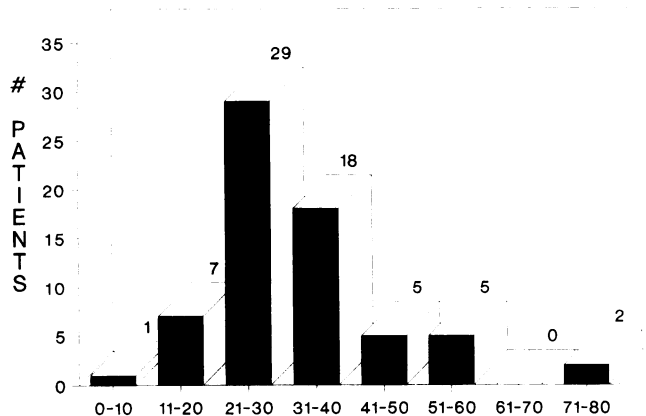


FIG. 1. Age of patients at time of accident (in years).

The average age of patients in this series was 31.9 years (range, 9 to 76 years) (Fig. 1). The mean age of those that required amputation was 33.5 years (range, 9 to 76 years), with one patient having bilateral amputations. There were 50 male and 17 female patients in the study group. The mechanisms of injury and amputation rates are listed in Table 1.

Pedal pulse deficits were documented in 36 limbs on arrival to the emergency room. Eighteen patients presented in shock, with a systolic blood pressure less than 90 mm Hg on arrival to the emergency room. Bone injuries were present in 51 limbs, muscle injuries in 57 limbs, and integument injuries in all limbs. Concomitant venous injury was present in 35 limbs. Nerve injuries were identified in 31 limbs. The mean interval from injury to the initiation of surgical intervention for the limb salvage group was 4.6 hours; in the amputated group, 5 hours. Combined vascular and orthopedic repair was undertaken in 29 limbs. Fasciotomy was performed in 22 patients.

This study specifically excludes limbs that were amputated in the field. The indications for reimplantation of these limbs has been established.^{1,2} When appropriate, data was submitted to statistical analysis using the Fisher's

TABLE 1. Mechanism of Injury and Amputation Rates

Type	No. Limbs	Salvaged	Amputated
Total Blunt	35	17 (49%)	18 (51%)
MVA	21	13 (62%)	8 (38%)
Fall	3	2 (67%)	1 (33%)
Avulsion	4	1 (25%)	3 (75%)
Crush	7	1 (14%)	6 (86%)
Total Penetrating	35	34 (97%)	1 (3%)
HVGSW	3	2 (67%)	1 (33%)
LVGSW	21	21 (100%)	0
SGW	3	3 (100%)	0
Stab	6	6 (100%)	0
Laceration	2	2 (100%)	0

MVA, motor vehicle accident; HVGSW, high-velocity gunshot wound; LVGSW, low-velocity gunshot wound; SGW, shot gun wound.

TABLE 2. Injury Level, Salvage, and Amputation Rates

Artery	No. Injuries	Salvage	Amputation
Common femoral	1	1 (100%)	0
Superficial femoral	21	15 (71%)	6 (29%)
Profunda femoris	3	3 (100%)	0
Popliteal	17	11 (65%)	6 (35%)
Infrapopliteal	29	22 (76%)	7 (24%)

exact probability test, chi square analysis, and Student's t test.

Results

Injuries were seen in the common femoral (1), superficial femoral (21), profunda femoris (3), popliteal (17), and infrapopliteal (29) arteries. One patient had injuries to both popliteal and infrapopliteal vessels. The level of injury, limb salvage, and amputation rates are shown in Table 2.

Thirty-six of seventy patients had documented pedal pulse deficits on arrival to the emergency room. Twenty-one (58%) limbs were successfully revascularized and salvaged; 15 (42%) limbs were amputated. Two of the fifteen amputated limbs had prolonged ischemia; one greater than 6 hours, the other greater than 15 hours. Eighteen (26%) patients presented in shock, with six patients ultimately requiring amputation, and 12 having successful limb salvage ($p > 0.05$). Thirty limbs presented with documented sensory or motor deficits in the emergency room. Operative findings showed 31 nerve injuries, including sciatic (10), combined common peroneal and tibial (11), tibial alone (2), common peroneal alone (5), and femoral (3) (Table 3). All 19 limbs amputated had nerve injuries, including sciatic (7), combined common peroneal and tibial (10), and common peroneal alone (2).

Bone injuries were identified in 51 limbs, 22 of which were of the Gustilo type III-C. This type of injury was described in 1984 as having an open unstable fracture, massive soft-tissue trauma, gross contamination, periosteal stripping, and associated vascular injury requiring surgical repair.³ Thirteen (59%) of the 22 type III-C frac-

TABLE 3. Nerve Injury, Salvage, and Amputation Rates

Nerve	No. Injuries	Salvaged	Amputation
Sciatic	10	3 (30%)	7 (70%)
Combined common peroneal and posterior tibial	11	1 (9%)	10 (91%)
Posterior tibial	2	2 (100%)	0
Common peroneal	5	3 (60%)	2 (40%)
Femoral	3	2 (67%)	1 (33%)
Associated sciatic nerve injury			

TABLE 4. *Associated Injuries—Amputated*

Type of Injury	Amputations (n = 19)
1. Vascular-arterial	19 (100%)
2. Vascular-venous	16 (84%)
3. Bone	19 (100%)
Type III-C	13
4. Nerve	19 (100%)
5. Muscle	19 (100%)
6. Ischemia > 6 hours	2 (11%)
7. Integument	19 (100%)
Requiring STSG or flap	17

STSG, split-thickness skin graft.

tures were amputated. All patients with a type III-C fracture and amputation had associated complete disruption of either the sciatic or tibial nerve ($p < 0.001$). Three amputated limbs had segmental bone loss greater than 3 cm, two had closed fractures, and a single patient had an open comminuted displaced fracture. In the limb salvage group, 25 patients presented with open fractures (type III-C [9]), and seven patients had closed fractures (two posterior knee dislocations). None of the patients with a type III-C fracture in this group had an associated nerve injury. Muscle injuries were present in 57 limbs. All extremities evidenced skin loss, with 26 limbs injured to the extent that split-thickness skin graft or flap repair would be required. Of those 26 limbs, nine were salvaged.

The mean time of injury to operative repair was 4.6 hours for the limb salvage group, and 5 hours for the amputated group ($p > 0.05$).

Combined vascular and orthopedic repair was undertaken in 29 limbs. Vascular repair preceded orthopedic repair in 23 patients (limb salvage, 19; amputated, four). Orthopedic repair preceded vascular repair in six patients (limb salvage, five; amputated, one). Those differences were not statistically significant ($p > 0.05$). Fasciotomy was performed in 22 patients (limb salvage, 19; amputated, 4). Concomitant venous injury was present in 35 limbs, of which primary amputation occurred in 8, and secondary or functional amputations in 8. Four of the eight patients with secondary or functional amputations had associated venous injury (three repaired, one ligated). Of those patients in whom limb salvage was achieved,

TABLE 5. *Associated Injuries—Limb Salvage*

Type of Injury	Limb Salvage (n = 51)
1. Vascular-arterial	51 (100%)
2. Vascular-venous	19 (37%)
3. Bone	32 (63%)
Type III-C	9
4. Nerve	12 (23%)
5. Muscle	38 (75%)
6. Ischemia > 6 hours	8 (16%)
7. Integument	51 (100%)
Requiring STSG or flap	9

STSG, split-thickness skin graft.

eight patients had ligation of infrapopliteal veins with no long-term sequelae. Twelve patients had either popliteal or superficial femoral venous injury, and all were repaired except four (one popliteal, and three femoral). Only three had mild edema at discharge (femoral vein group).

Associated injuries in the salvaged and amputated groups are shown in Tables 4 and 5.

TABLE 6. *Limb Salvage Index Scoring System*

Location	Points	Extent of Injury
Artery	0	Contusion, intimal tear, partial laceration or avulsion (pseudo-aneurysm) with no distal thrombosis and palpable pedal pulses; complete occlusion of one of three shank vessels or profunda.
	1	Occlusion of two or more shank vessels, complete laceration, avulsion or thrombosis of femoral or popliteal vessels without palpable pedal pulses.
	2	Complete occlusion of femoral, popliteal, or three of three shank vessels with no distal runoff available.
Nerve	0	Contusion or stretch injury; minimal clean laceration of femoral, peroneal, or tibial nerve.
	1	Partial transection or avulsion of sciatic nerve; complete or partial transection of femoral, peroneal, or tibial nerve.
	2	Complete transection or avulsion of sciatic nerve; complete transection or avulsion of both peroneal and tibial nerves.
Bone	0	Closed fracture one or two sites; open fracture without comminution or with minimal displacement; closed dislocation without fracture; open joint without foreign body; fibula fracture.
	1	Closed fracture at three or more sites on same extremity; open fracture with comminution or moderate to large displacement; segmental fracture; fracture dislocation; open joint with foreign body; bone loss < 3 cm.
	2	Bone loss > 3 cm; Type III-B or III-C fracture (open fracture with periosteal stripping, gross contamination, extensive soft tissue injury-loss).
Skin	0	Clean laceration, single or multiple, or small avulsion injuries, all with primary repair; first degree burn.
	1	Delayed closure due to contamination; large avulsion requiring STSG or flap closure. Second and third degree burns.
Muscle	0	Laceration or avulsion involving a single compartment or single tendon.
	1	Laceration or avulsion involving two or more compartments; complete laceration or avulsion of two or more tendons.
	2	Crush injury.
Deep Vein	0	Contusion, partial laceration, or avulsion; complete laceration or avulsion if alternate route of venous return is intact; superficial vein injury.
	1	Complete laceration, avulsion, or thrombosis with no alternate route of venous return.
Warm Ischemia Time	0	<6 hours
	1	6–9 hours
	2	9–12 hours
	3	12–15 hours
	4	>15 hours

STSG, split-thickness skin graft.

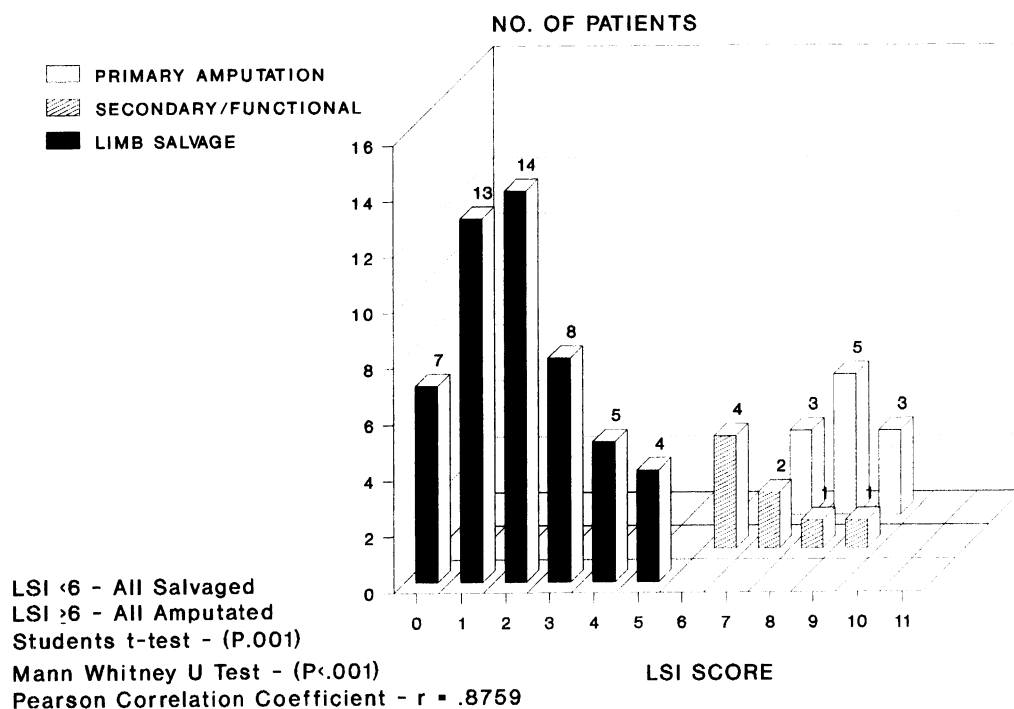


FIG. 2. Limb salvage index distribution.

A limb injury index was developed based on skin injury (0 to 1 points), muscle injury (0 to 2 points), bone injury (0 to 2 points), nerve injury (0 to 2 points), vein injury (0 to 1 points), arterial injury (0 to 2 points), and length of warm ischemia time (0 to 4 points) (Table 6).

Seventy limbs were scored with the limb injury index. All patients with scores less than 6 had limb salvage achieved. All 19 in the amputated group had scores of 6 or greater (Student's *t* test: $t = -14.97$ [$p < 0.001$], Mann-Whitney U Test [$p < 0.001$], Pearson correlation coefficient [$r = 0.8759$] [Fig. 2]). Three cases are presented to further illustrate the use of the limb salvage index.

Case Reports

Case 1

A 19-year-old man involved in a hunting accident was shot with a 30-06 rifle in the right lower extremity at the level of the trifurcation. The patient had massive soft tissue loss, avulsion of the posterior tibial and common peroneal nerves, transection of the trifurcation vessels with thrombosis of the distal popliteal artery, transection of two tibial veins, and an open-comminuted displaced fracture of the proximal tibia and fracture through the femoral condyle (Fig. 3). On arrival to the emergency room, warm ischemia time was documented to be 8 hours 15 minutes. The patient was taken to the operating room, where a multidisciplinary team approach was used. Revascularization of the foot was achieved, external fixation of fractures accomplished, and wounds were initially packed open because of contamination. The patient remained hospitalized for 52 days. He underwent surgery on four occasions by the orthopedic service, and on two occasions by the plastic surgery service, the last of which was a flap closure of his wounds. Over the next 18 months, the patient was hospitalized on four occasions for bony non-union, development of osteomyelitis, and partial flap failure. Throughout this period, the patient had what is designated as a functional amputation.



FIG. 3. Rifle injury resulting in a complete occlusion of the distal popliteal artery with collateral flow around the knee. Comminuted-displaced fracture of the proximal tibia. Note the presence of soft-tissue air.

Approximately 20 months after initial injury, the patient was returned to the operating room and underwent an above-knee amputation because of bony non-union and an insensate foot with absence of motor function. The patient was ambulating on a prosthesis in 2 months, and had returned to work in 3 months. His limb salvage index score was 8.

Case 2

A 21-year-old woman involved in an industrial accident was gored by a forklift through the right thigh, resulting in a massive degloving-type soft tissue injury, a comminuted open femur fracture, and an avulsion of her superficial femoral artery and vein (Figs. 4 and 5). Warm ischemia time was less than 6 hours. She was also noted to have a right inferior ramus fracture of the pelvis. The patient was taken to the operating room, where a multidisciplinary team approach was used. She had flow restored to the distal extremity initially with indwelling vascular shunts and stabilization of the femur fracture with external fixation. The sciatic nerve was explored and noted to be contused but intact. A reverse saphenous vein graft was used both for the arterial and the venous repair. The graft was covered and the wound was left open. The patient was returned to the operating room on three occasions for irrigation and debridement. The third operation included internal fixation of the femur, reapproximation of soft tissues, and a split-thickness skin graft. The patient was hospitalized for 36 days, and ambulated with a walker on hospital day 30. Seven months after her initial hospitalization, a follow-up examination showed that all wounds had healed. She was ambulating

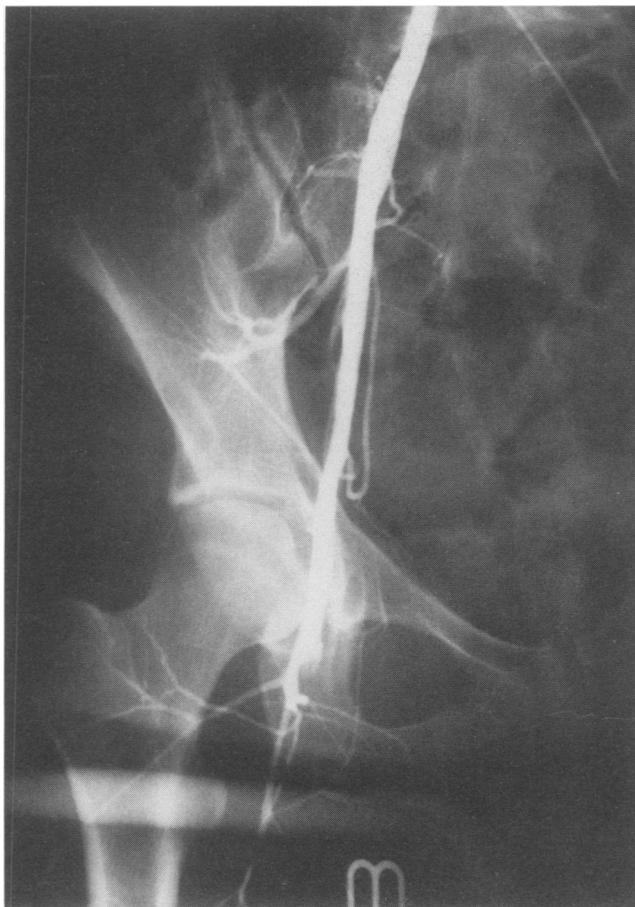


FIG. 4. Avulsion of the superficial femoral and profunda femoris arteries as a result of being gored by a forklift through the proximal thigh.

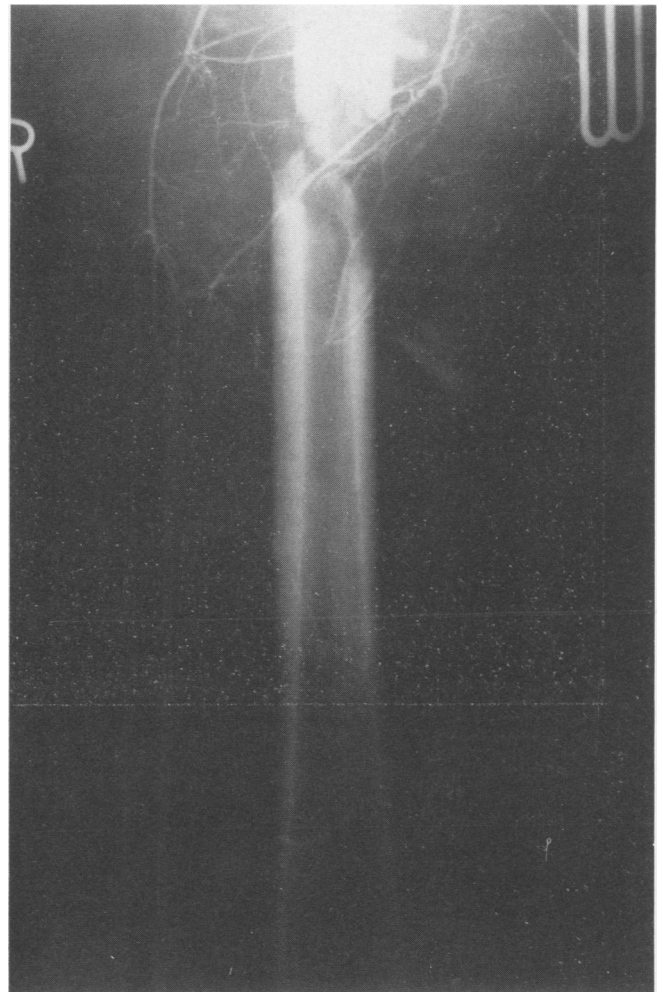


FIG. 5. Arteriogram showing absence of flow through the superficial femoral artery with sparse collateralization. Proximal displaced femur fracture with bone fragment noted distal to the fracture site.

without assistance and had returned to nursing school. The patient's limb salvage index score was 5.

Case 3

A 15-year-old girl sustained a crush injury to the left lower extremity and distal tibial region when she was hit by a truck. She presented with a partial amputation of the left lower extremity with segmental bone loss of approximately 5 cm, avulsion of the common peroneal and posterior tibial nerves, avulsion of all infrapopliteal vessels, a degloving injury to the skin, and crush injury to the muscle with tendon involvement at the ankle (Fig. 6). She was 12 weeks pregnant. Orthopedic and plastic surgery attempted a combined repair. She had repair of the posterior tibial neurovascular bundle using microsurgical techniques, including bone shortening with application of an external fixator (Fig. 7). A fasciotomy of the foot was performed. Her wounds were packed open, and she remained in the intensive care unit for 5 days. She returned to surgery on three occasions for irrigation and debridement. The limb was declared non-viable by the fifth postoperative day. She underwent a below-knee amputation on the seventh postoperative day, and was discharged 4 days later. She was ambulating on a prosthesis 2 months later. The patient's limb salvage index score was 9.



FIG. 6. Splint has been applied; however note the comminuted fracture of the distal tibia with marked bone loss just proximal to the ankle.

Discussion

In developing the limb loss index, we did not want to burden the surgeon with one more scale to use in the assessment of a trauma patient. We believe, however, that we have developed a guide for accurately evaluating trauma to the lower extremity, taking into consideration the systems involved and the degree of severity of injury to these systems. This index can assist the surgeon in making a decision as to the viability of an injured limb and the likelihood of success in salvaging the limb.

Amputation rates associated with traumatic arterial injuries range from 20% to 50%.⁴⁻⁷ In this series the amputation rate in severely traumatized extremities was 27%. Blunt injuries carried a higher amputation rate, with 18

(51%) of 35 limbs amputated, as compared with penetrating trauma, where only one (3%) of 35 limbs required amputation ($p < 0.001$). Of those patients with blunt injuries, the most severe were crush/avulsion injuries, in which nine (82%) of 11 patients ultimately had limbs amputated ($p < 0.03$). Of the variables identified to predict limb salvage, there was no difference between the amputee group and limb salvage group when we looked at the presence or absence of shock, the time of injury to operative repair, or the order of vascular and orthopedic repair. We did find that the absence of pedal pulses on arrival, in association with the severe soft tissue, bone, and nerve injuries seen in these extremities, was more indicative of a poor outcome than when pulses were present with this type of injury.

Only one patient in this series presented with a pedal pulse deficit and prolonged ischemia for more than 12 hours. This patient ultimately required amputation after limb salvage was attempted. To save an extremity, it is imperative that there be early recognition of arterial injury. Miller and Welch⁸ have documented in a canine model a salvage rate of greater than 90% with ischemic periods

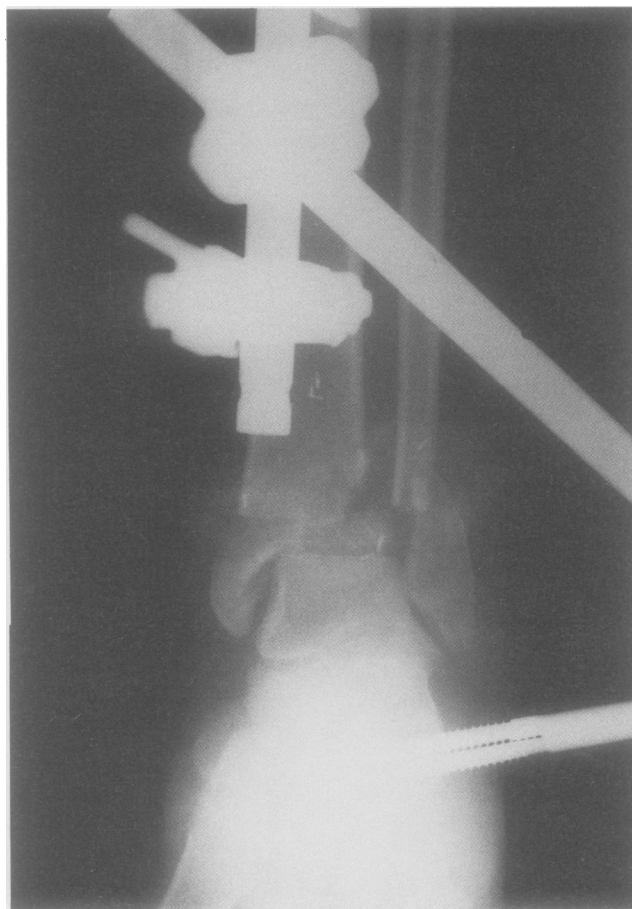


FIG. 7. The bone has been shortened and external fixator applied to stabilize the ankle.

of less than 6 hours. His limb salvage rates were less than 50% with ischemia of greater than 12 hours. The importance of this variable in the traumatized extremity and its potential for poor outcome with prolonged ischemia is emphasized in our limb salvage index (0 to 4 points).

Peripheral nerve injuries were present in all patients in the amputated group. Ninety-five per cent of limbs that were amputated had complete transection or avulsion of the sciatic, tibial, or peroneal nerve. The association of permanent nerve deficits with ultimate amputation is well documented.^{6,9-15} The most severe deficits are those associated with sciatic injuries at the level of the hip with denervation of the hamstrings, tibial, and common peroneal nerves, leading to 100% limb disability.¹² The next most severe is a complete tibial nerve injury at the level of the knee, which is associated with a 60% to 70% limb disability.¹² Recognition of a posterior tibial nerve injury is particularly important, as it leads to the loss of plantar sensation, paralysis of intrinsic foot musculature, and frequently to neuropathic ulcerations.¹²⁻¹⁵

Severe bone injuries to the lower extremities have devastating consequences. In 1969 Gustilo designated compound fractures as types I, II, and III.¹⁶ In 1984, Gustilo et al.³ further subdivided type III injuries into III-A, III-B, and III-C, based on the injury and the order of worsening prognosis. The severity of a type III-C fracture alone is reflected by amputation rates that range from 42% to 78%.^{3,17}

Twenty-two limbs in this series had Type III-C fractures, 13 (59%) of which ultimately required amputation, and nine (41%) of which were salvaged. The difference in amputation rates was a function of associated nerve injury with this severe type of fracture. All patients undergoing amputation with a type III-C fracture had complete disruption of either the sciatic or tibial nerves. This emphasizes the potential for poor outcome with these types of injuries, especially in combination with extensive nerve injury. Absolute indications for primary amputation with type III-C injuries have been proposed by Lange et al.¹⁸ and supported by Caudle and Stern.¹⁷ This series does support the indication for primary amputation of type III-C injuries in association with irreparable tibial nerve injury.

The timing of vascular repair and stabilization of various orthopedic injuries remains controversial. Many authors have stressed the importance of initial fracture stabilization followed by vascular repair to prevent possible disruption of a vascular anastomosis during fracture stabilization.¹⁹⁻²¹ Others have advocated the use of shunts for peripheral arterial injuries to reestablish blood flow to the distal extremity, followed by fracture stabilization and then definitive vascular repair.^{19,22-24} Although our study did not show a difference in outcome with regard to the order of repair, it is our senior author's recommendation

that one proceed with vascular repair or shunting to reestablish perfusion to the affected extremity before fracture stabilization. The general/vascular surgeon should remain involved in the procedure to protect or revise the vascular repair and assure adequate soft tissue coverage of the repair after fracture stabilization.

Perry et al.^{25,26} have clearly defined the pathophysiology of compartment syndromes. The indications for fasciotomy are well documented in the literature.²⁷⁻²⁹ In this series fasciotomy was performed in 17 (33%) of 51 patients who had limb salvage achieved and in five (63%) of eight patients with either secondary or functional amputation. Although these numbers appear small, they do not include the majority of patients who presented with self-induced fasciotomy as a result of their injury. Vitale et al.³⁰ have shown fasciotomy to be a safe adjunctive procedure in limb salvage with very little morbidity. All extremity injuries of this magnitude should have some type of compartmental release to allow for expansion of the respective tissues.

Many stress the inherent risk of amputation with an arterial injury below the knee.³¹⁻³³ Howe et al.³¹ emphasized this in their system for scoring arterial injuries, with an amputation rate of 80%. A cumulative amputation rate of 18% has been noted in various reports of infrapopliteal injuries.^{32,34-37} In this series the risk of amputation after infrapopliteal injury closely approximates that previously reported, with seven (24%) of 29 infrapopliteal injuries ultimately leading to amputation. We did find, in those seven extremities with infrapopliteal vascular injuries, multiple associated injuries. We found that the degree of total injury to the extremity correlates with the potential for amputation to a greater extent than did the level at which arterial injury occurred alone.

Summary

Based on the analysis of 70 lower extremity injuries involving multiple systems, a limb salvage index was derived. By careful initial and operative evaluation of vascular, nervous, bone, soft tissue, and venous systems, as well as warm ischemia time, it was possible to more closely predict limb salvage.

Amputation, although never the primary goal of the physician, may well be the procedure of choice in some cases. By proceeding with primary or early secondary amputation, it is often possible to quickly return a healthy productive individual back to society rather than have the patient suffer from a chronic nonfunctional state.

Although surgeons tend to become enamored of technical advances in the provinces of the surgical subspecialties, we must remain cognizant of the overall long-term result to the patient. The patient may be better served with a primary amputation, as failure in this setting may

induce serious psychological and financial hardships on the patient and his family.

Absolute indications for amputation from this study include (1) a patient with a limb salvage index of 6 or greater ($p < 0.001$), and (2) a patient with Gustilo type III-C fracture with associated nerve injury ($p < 0.001$). A relative indication is a patient with a severely traumatized extremity and associated sciatic or tibial nerve injury.

Numbers cannot replace clinical judgment. This index can be a valuable objective tool, however, in the evaluation of the patient with a severely traumatized extremity. By more accurately identifying the patient who would most benefit from "heroic" multispecialty efforts, the surgeon can assure a more proper outcome and appropriate use of resources.

Acknowledgments

The authors thank Judy Green, Deborah Bley, Pat Kassebaum, and Michael Bideman, Ph.D., for their invaluable assistance in preparation of this manuscript.

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DISCUSSIONS

DR. MALCOLM PERRY (Nashville, Tennessee): This is obviously an extremely difficult decision. Most of us feel that it's possible to save the majority of limbs; and those of us in vascular surgery almost always can revascularize the limb if we are willing to accept some limb shortening.

The average age of these patients was 31 years; therefore one would anticipate, for the most part, that the vascular system could be revascularized. There should not be a great deal of atherosclerosis.

Early in my limb replantation experience I made the mistake of replanting a lower limb in a patient who had it blown off by an explosion of acetylene and oxygen. The limb survived, but he ended up with an